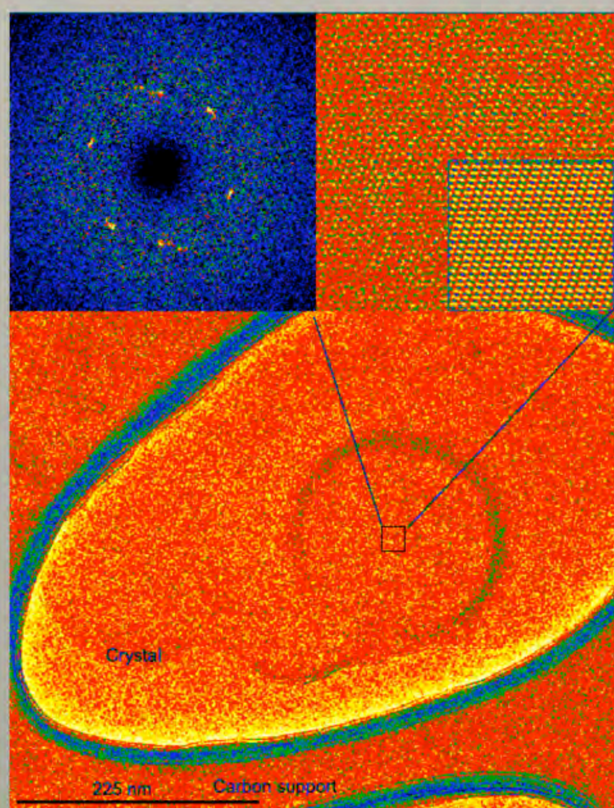
SofTEAM

WORKSHOP REPORT - March 8, 2010

National Center for Electron Microscopy



Lawrence Berkeley National Laboratory

On the Cover: The TEAM project, concluded in 2009, delivered next generation electron microscopes of unprecedented resolution and sensitivity to NCEM. Preliminary experiments with soft matter imaging reveal the possibilities of direct imaging of crystallized molecules. The cover shows a 2 nm thin crystal of D5TBA (Decyl Pentathiophene Butyric Acid) that extends laterally over hundreds of nanometers (bottom image). The TEAM 0.5 microscope allowed for direct imaging of the local crystal structure with near atomic resolution. Crystallographic image processing was applied to recover an average structure from the noise-dominated data (inset top right). A diffractogram of the crystal is show in the top left.

— *Figure courtesy of F. Martin, A. Katan, S. Aloni, M. Salmeron, MSD, LBL*
B. Jiang, C. Kisielowski, NCEM, LBL

Report on the SofTEAM Workshop

Location: Lawrence Berkeley National Laboratory

Materials Science Division

Building 66 Auditorium

Date: March 8, 2010

Organizers: U. Dahmen, C. Kisielowski, A.M. Minor, (NCEM, LBL)

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Invitation

SofTEAM Workshop

Monday, March 8, 2010
9AM-5PM, LBL Building 66 Auditorium

This workshop is being sponsored by the National Center for Electron Microscopy to discuss future possibilities related to the electron microscopy of soft materials. Our intention is to build on the success of the TEAM project with an instrument that is specialized for soft materials and in particular soft/hard interfaces. The primary focus of the workshop is a discussion of the scientific needs and opportunities for microcharacterization of interfaces between soft and hard materials in the context of recent advances in instrumentation such as phase plates, cryostages, detectors, and developments in imaging techniques.

Invited Speakers:

Manfred Auer, JBEI, LBL
Jim DeYoreo, Molecular Foundry, LBL
Ken Downing, LBL
James Evans, U.C. Davis
Heinz Frei, LBL
Bob Glaeser, U.C. Berkeley & LBL
Hiroshi Jinnai, Kyoto Institute of Technology, Japan
Bernd Kabius, Argonne National Laboratory
Matthew Libera, Stevens Institute of Technology
Abbas Ourmazd, University of Wisconsin, Milwaukee
David Prendergast, Molecular Foundry, LBL

Those interested in attending should email Jane Cavlina (JLCavlina@lbl.gov). Speakers will be by invitation only, but participation in the workshop through discussion sessions is encouraged for all interested individuals.

Program

Time	Speaker	*Title*
9:00-9:15	Miquel Salmeron, MSD Director	*Welcome and Introduction to MSD*
9:15-9:45	Ulrich Dahmen, NCEM Director	*The TEAM Project and Future Directions at NCEM*
9:45-10:15	Keynote: Hiroshi Jinnai, Kyoto Institute of Technology	*Electron Tomography of Soft Polymeric Materials*
10:15-10:35	— *Working Break* —	
10:35-10:55	Manfred Auer, JBEI & LBL	*Electron Tomography in Lignocellulose Biofuel Research*
10:55-11:15	Jim DeYoreo, MF, LBL	*Scientific Challenges in Understanding Assembly within Biomineral and Biomimetic Materials Systems.*
11:15-11:35	Nitash Balsara, UCB & LBL	*Imaging Electrolyte-Electrode Interfaces*
11:35-11:55	Heinz Frei, Helios, LBL	*Artificial Photosynthetic Systems*
11:55-1:00	— *Lunch* —	
1:00-1:30	Keynote: Matthew Libera, Stevens Institute of Technology	*Spectroscopic Imaging of Hydrated Materials*
1:30-1:50	David Prendergast, MF, LBL	*First-principles Simulations of Damage in Materials Induced by Core-Level Excitations*
1:50-2:10	Abbas Ourmazd, UWM	*Divide & Conquer: EM of Radiation-Sensitive Materials*
2:10-2:30	Bob Glaeser, UCB & LBL	*Phase Plate Developments for Biological Structures*
2:30-2:50	— *Working Break* —	
2:50-3:10	James Evans, UC Davis	*Imaging Biological Processes with an Aberration Corrected Dynamic TEM.*
3:10-3:30	Peter Denes, LBL	*Modern Detectors for Electron Microscopy of Soft Materials*
3:30-3:50	Bernd Kabius, ANL	*Application of a Chromatic Aberration Corrector for Biological Materials*
3:50-4:10	Christian Kisielowski, NCEM, LBL	*Contrast enhancement in electron microscopy: From resolution to time evolution*
4:10-4:30	Ken Downing, LBL	*State of the Art in Cryo TEM*
4:30-5:00	— *Open Discussion* —	

Executive Summary

The SofTEAM workshop was held at the Lawrence Berkeley National Laboratory on March 8, 2010 in order to identify scientific opportunities and to seek input from the scientific community regarding advanced instrumentation for electron microscopy of soft/hard interfaces. The workshop was intended to discuss the scientific issues and opportunities for imaging of soft matter and hybrid materials, a crucial area that is not well covered by existing TEM instruments. Several of these opportunities, which will be described in this report constitute a compelling reason for proposing the development of a dedicated instrument to close an existing gap for investigations of composite materials that contain hard and soft components. The initiative builds on the success of the TEAM project, which led the development of next generation electron microscopes with unprecedented capabilities in terms of resolution and sensitivity. In the context of the scientific problems important to basic energy research, the workshop addressed the opportunities that would result from advancing the instrumentation and techniques related to electron microscopy at the interface between soft and hard matter.

The design and discovery of new hybrid materials is becoming increasingly important in the nation's search for new sustainable energy technologies. Development of new energy-related devices such as organic/inorganic photovoltaics, fuel cells or batteries requires that we advance our fundamental understanding of such materials, placing new demands on scientific tools for characterization.

Electron scattering offers the opportunity to advance our basic knowledge of materials and phenomena by characterizing their constituents at high spatial resolution. This workshop highlighted numerous scientific challenges for electron scattering, ranging from 3D tomographic imaging of block copolymers to understanding and controlling the mechanisms of biomineralization, or the imaging of novel organic thin films. However, soft and hard constituents require very different approaches and instrumentation. The disparity between these approaches became clearly apparent in the course of the workshop, stressing the growing need to close the gaps in technique and instrumentation. For instance, the sophisticated low-dose imaging and data analysis techniques developed by the biological community could be of tremendous benefit to an understanding of functionalized nanocrystals on inorganic substrates. Conversely, the development of high-sensitivity detectors from the TEAM project is apt to be of great advantage to the imaging of organic materials.

The workshop discussion of the technical challenges highlighted the great potential for leveraging the investment made in the aberration-corrected instrumentation developed under DOE's TEAM project. Imaging the soft/hard interface in composite materials with increased signal-to-noise ratios and sensitivity was a clear goal for all participants. The outstanding problem in attaining this goal remains electron dose limited resolution, which determines the temporal and spatial resolution at which the structure of soft matter can be imaged, chemically characterized, or probed by in-situ experiments. A SofTEAM microscope would target these limits with a unique combination of technologies. The microscope would take advantage of existing components such as spherical and chromatic aberration correctors and components that are yet to be developed such as advanced cryogenic stages, phase plate technologies and direct electron detectors. Such an instrument would provide a resource for the growing community of nanoscience researchers investigating hybrid materials containing both hard and soft matter components by offering unique capabilities not currently available anywhere else.

Workshop Report

Background

This meeting built on a series of previous workshops organized to establish underlying scientific needs that drive future development of techniques and instrumentation for electron microscopy. These workshops provided the intellectual framework and the scientific underpinning for the development of the next generation of electron microscopes, realized under the TEAM Project (Transmission Electron Aberration-corrected Microscope). Based on the technical specifications from feedback by the scientific community at these workshops, the TEAM Project was completed in 2009 when the TEAM microscope began operations as a user instrument at NCEM.

The TEAM Project was envisioned as a staggered sequence of instruments located at different DOE partner labs, each optimized for a specific application such as high-resolution imaging, single-atom spectroscopy, fast dynamics and in-situ probing of materials properties in an aberration-free environment. The successful completion of the first TEAM project after an intense five-year collaboration has established the ability of the microscopy community to carry out complex development projects of a larger scale and opened the door to future electron scattering projects in the US and abroad.

To explore emerging scientific challenges and opportunities for future developments in electron scattering instrumentation and technique, a DOE-BES workshop was held in 2007, entitled *Future Science Needs and Opportunities for Electron Scattering: Next-Generation Instrumentation and Beyond*. By involving a cross section of the scientific community this workshop examined high-priority research directions in electron scattering. The meeting identified a number of important needs, ranging from electron-optical environments for in-situ experimentation to better detectors and improved time resolution for dynamics. The report from this workshop is available at [http://www.sc.doe.gov/bes/reports/archives.html]. The following issues emerged as the most important scientific themes during the meeting:

- The nanoscale origin of macroscopic properties
- The role of individual atoms, point defects, and dopants in materials
- Characterization of interfaces at arbitrary orientations
- The interface between ordered and disordered materials
- Mapping of electric and magnetic fields in and around nanoscale matter
- Probing of structures in their native environments
- The behavior of matter far from equilibrium

Each of these themes was underscored by a set of scientific challenges that are beyond the reach of current technologies, and that provide scientific drivers for new developments in instrumentation, theory and technique.

A particularly important issue identified in the workshop was the interface between ordered and disordered materials. Under the heading *Order and Disorder: Crystals Interacting with Liquids, Vapors, and Soft Materials*, the report states:

> *"The role of interfaces in governing physical properties and dynamic behavior of materials is omnipresent. Electron scattering techniques have been very successful in providing important contributions toward understanding solid-solid interfaces. Also, in areas focusing on noncrystalline materials, particularly in the life sciences, microscopy has made a strong impact. However, tremendous opportunities exist where only the first small steps have been taken; interfaces where crystals are in contact with less ordered states of matter have remained a challenge.*
>
> *Understanding solid-vapor, solid-liquid, and hard-soft interfaces is the key to progress in a number of important fields, including energy conversion, catalysis, the life sciences, electronics, and engineered materials.*
>
> *…. In the life sciences as well as in other fields, including electronics, being able to visualize nanoscale amorphous and nanocrystalline materials with interface specificity is a crucial goal. Can we achieve atomic-level imaging of proteins, cells, viruses, and nano-bio composites while maintaining them in their natural states? How might we detect and quantify functional components and interactions with drugs, targeting agents, and imaging agents? Seventy percent of drug molecules interact with membrane proteins, most of which cannot be crystallized; thus, solving the structure of proteins that cannot be crystallized by imaging individual proteins via real-space and reciprocal-space methods is an unmet and valuable challenge. The priority developments identified in this workshop will provide a pathway toward understanding many of these issues."*

The growing potential for hybrid materials involving hard-soft interfaces is underscored by developments in photovoltaics, solid-state fuel cells or batteries based on nanocrystals and polymers. However, the electron-optical characterization of such materials remains limited by the dichotomy between biology and materials approaches to electron microscopy, which requires different instrumentation and techniques.

The SofTEAM workshop was organized to explore the scientific needs for characterization of materials containing hard-soft matter interfaces and to establish how recent advances in instrumentation and techniques under the TEAM project can be leveraged to support the need for electron beam microcharacterization of such hybrid materials.

The workshop was structured to discuss scientific challenges first and then address technical and instrumental considerations. The event concluded with an open discussion period in which the advantages and disadvantages of specific components were discussed with all participants. Below, we have summarized the findings from the presentations and the discussion in two groups - scientific opportunities and technical challenges.

Scientific opportunities

- *Polymeric materials* bring an array of rich morphological problems at length scales requiring nanoscale spatial resolution, which is limited by dose. Applications include the development of new batteries, solar cells, microelectronics, and functionalized membranes. Scientific challenges in these systems range from the mapping of their water content to a characterization of the extended interfaces in block copolymers and metal/polymer interfaces. Contrast enhancement is needed since staining processes are known to introduce artifacts and limit resolution. Electron tomography at improved resolution is being developed to better understand the complex three-dimensional network structure of polymers, which is a key to their versatile functionality.

- *Biomineralization* is a rapidly evolving research area that strives to utilize nature-inspired templates to provide new approaches to self-organization and the synthesis of new materials. The exact nature of the soft/hard interface in these materials can critically determine the physical and chemical properties of such materials. Advanced techniques of electron microscopy could dramatically change the future structural and chemical characterization of these interfaces.

- *Hybrid organic/inorganic photovoltaic devices and artificial photosynthetic systems* currently being developed are aimed at obtaining more sustainable energy technologies. For low-cost solutions, abundance of raw materials and scalability of synthesis are important parameters that have a large impact on this research field. As a result, such materials systems typically contain hard, soft, and radiation sensitive components of nanoscale dimensions. The resulting structure at the interface between these materials is poorly understood at present, but this interface has a great effect on device efficiencies.

- *Novel organic thin films* made from crystallized molecules or bioinspired polymers (peptoids) hold the promise that they can be functionalized to aid the development of soft materials electronics, substrates, or membranes. Their thickness of only a few nanometers makes such films accessible to atomic resolution imaging, which is nonetheless dose limited. Low dose imaging with atomic resolution may become feasible but requires development of suitable techniques and instrumentation to obtain an optimized signal-to-noise ratio at a minimal electron dose.

- *New strategic directions* within the Department of Energy, such as the Carbon Cycle 2.0 initiative at LBNL will require addressing soft and hard matter on equal footing. Traditionally, the NCEM is well equipped for structural and chemical analysis of hard materials. There is however a great need for applying leading edge imaging, spectroscopy, tomography and in-situ experiments to soft materials.

Technical challenges

- *Contrast enhancement* adapted to specific materials is an important technical goal that requires an instrument capable of operating in a broad range of electron optical conditions. Recent advances in aberration correction allow harvesting high spatial frequencies to limits set by beam-sample interactions and by the physics of the underlying Coulomb scattering process itself. Further development of emerging phase plate technologies and the utilization of Cc correction will boost the collection of low spatial frequencies, which are especially important for soft matter. Moreover, contrast-enhanced imaging of soft materials in the low-loss region will be directly enabled by Cc correction. As a result, signal collection can be optimized to match both the chemistry and the dimension of the objects under investigation.

- *Signal detection* is an important part of the next frontier for electron microscopy. Current strategies include the development of radiation-hard fast detectors, the design of contrast transfer functions in aberration corrected microscopes, and an optimal signal collection that will minimize the noise level for a given dose. A new theoretical approach to faint-signal data analysis holds great promise for bridging the gap between biological and materials imaging and for quantifying dynamics and conformational changes of molecules.

- *Computational efforts* should be strengthened because it is expected that faster signal detection, time dependencies and electron tomography will generate large data sets that can no longer be evaluated by a visual inspection of single images. Additionally, a complementary effort in the simulation of beam-sample interactions would be advantageous for understanding dose limitations and consequences.

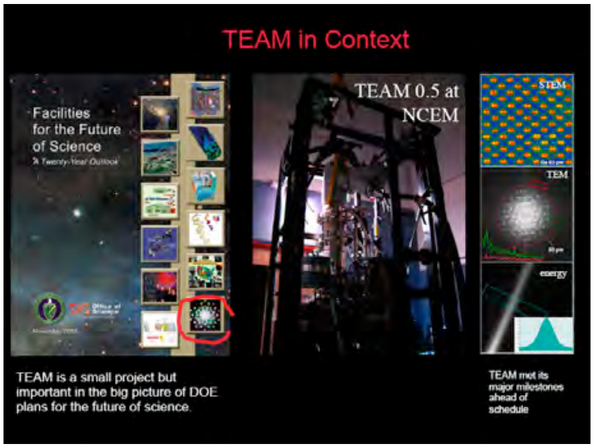
- *Cryogenic stages* need to be developed to allow ultra-stable measurements and imaging at high resolutions combined with tomographic capabilities. Strategies to investigate soft/hard interfaces will have to use low dose techniques and rely on ultra-stable stages at cryogenic temperature to minimize the deleterious effects of drift and contamination.

Summary of Presentations

Miquel Salmeron
MSD Director

Welcome and Introduction to MSD

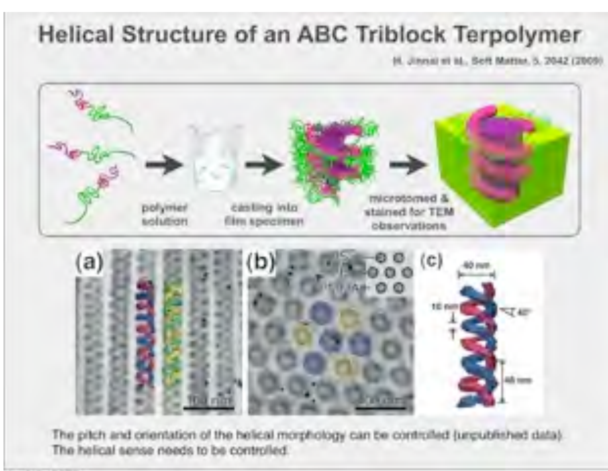
- LBNL's mission under the Carbon Cycle 2.0 initiative addresses scientific aspects of energy research ranging from generation to utilization and conservation of energy. Materials play a key role in future energy technologies.
- Research in the Materials Sciences Division aims to develop a basic understanding of materials, and to invent or discovery new materials and new methods of synthesizing materials.
- The development of new tools for characterization and theory for modeling is essential for understanding materials properties and predicting or controlling their behavior.
- MSD encompasses three scientific user facilities for synthesis and characterization of materials – the Molecular Foundry, the Center for X-ray Optics and the National Center for Electron Microscopy.
- The present workshop addresses the scientific challenges at the interface between hard and soft matter components in hybrid materials and the resulting needs in electron microscopy instrumentation and technique.



Ulrich Dahmen
NCEM Director

The TEAM Project and Future Directions at NCEM

- TEAM has been a highly visible project, a First for the microscopy community, and a part of DOE's 20-year road map for Facilities for the Future of Science.
- Major advances in instrumentation developed under TEAM, such as the chromatic aberration corrector, piezo-stage, CMOS detector, high-brightness gun etc. offer new technologies that benefit the broader microscopy community.
- The TEAM project exemplifies the role of national labs and mid-size user facilities, and the instrument is available for user operations at NCEM.
- Based on the technological know-how developed under the TEAM project, the SofTEAM proposal offers a unique approach to bridging the gap between instrumentation needed for imaging of hard and soft matter. The ability to image interfaces in novel hybrid materials like nanocrystal-polymer photovoltaics, batteries or fuel cells will play an important role in materials research for new energy technologies.

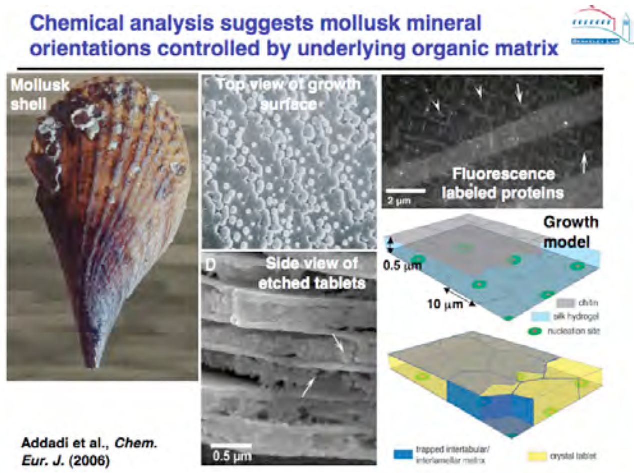


Hiroshi Jinnai
Kyoto Institute of Technology

Electron Tomography of Soft Polymeric Materials

- Methods to enhance contrast, such as phase imaging, are very important for the future of soft-materials characterization.
- In hierarchical soft-materials, mesoscale 3D imaging is as important as nano-scale 3D imaging.

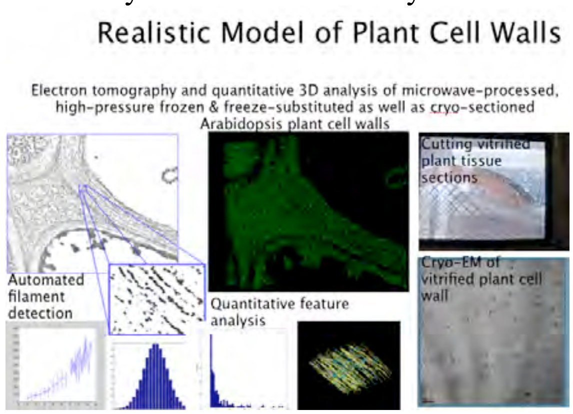
- Cc correction may be more significant than Cs correction because the sample thickness is generally thicker in soft materials than in hard materials (plus, we are not presently limited by instrument resolution in soft matter microscopy).
- Methods to reduce electron dose, such as an improved minimum dose system and higher sensitivity detector are critical.



Jim DeYoreo
MF & LBNL

Scientific Challenges in Understanding Assembly within Biomineral and Biomimetic Materials

- Biomineralization is an inspiration to materials scientists and a key process in human health and environmental science.
- Typically, an organic matrix and mineral are in intimate contact. Presently, there is little information from the soft side of these systems.
- The initial stages of the interface must be accessed to understand formation and growth.
- Dynamics in hard/soft systems need to be understood as well.



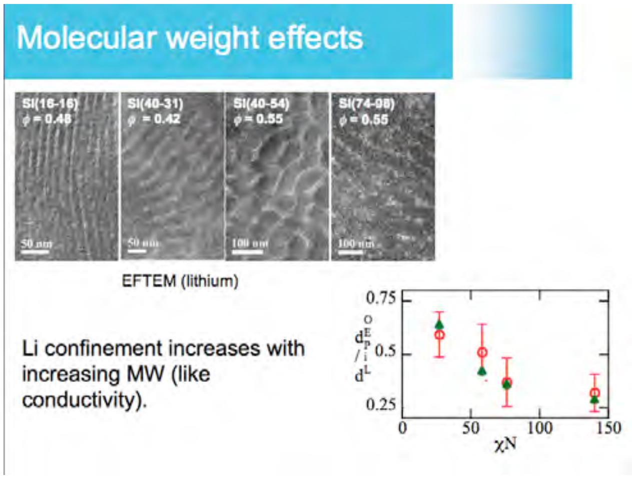
Manfred Auer
JBEI & LBL

Electron Tomography in Lignocellulose Biofuel Research

- Sample preparation is key for successful analysis. When enhancing contrast it is necessary faithfully preserve the sample, which can be done through high-pressure freezing, freeze-substitution or cryo-sectioning. Sample preparation will be even more critical when trying to preserve both hard and soft materials.
- Large Fields (wide-field) imaging seems necessary to get statistically meaningful information, in three dimensions if possible.
- Computational analysis will be needed to deal with complex biological data sets.
- More eyes and ears (detectors) on the sample would be highly beneficial, e.g. allowing for elemental mapping or more exotic methods such as a Fluorescence or

Raman detector.

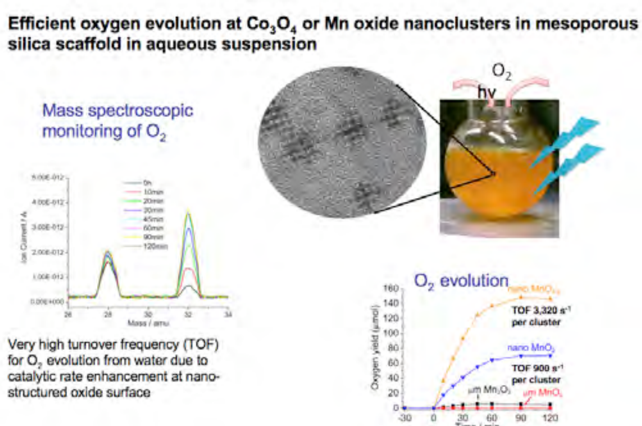
- Many problems are multiscale in nature.



Nitash Balsara
UC Berkeley & LBNL

Imaging Electrolyte-Electrode Interfaces

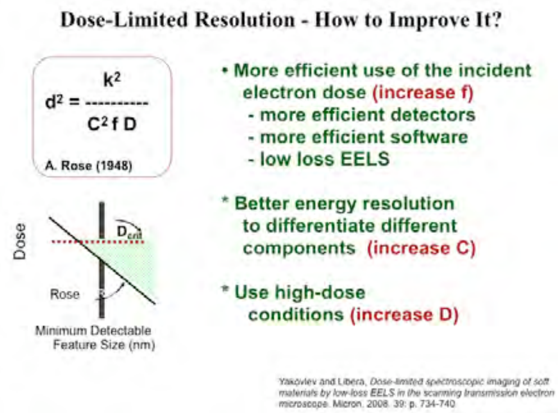
- Imaging structure of block copolymer domains at the interface is crucial.
- Watching the interface evolve during charge-discharge cycles would be even better.
- Could the presence of a metal enable higher than usual resolution near the surface?
- Imaging the interface with chemical specificity requires technique development.
- If we could image the origin of reduced conductivity in battery electrolytes we could obtain true insight into the origin of battery failure.



Heinz Frei
Helios SERC & LBL

Artificial Photosynthetic Systems

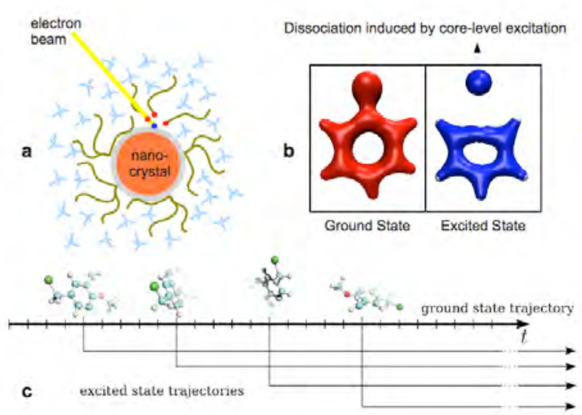
- The understanding of soft/hard interfaces in artificial photosynthetic systems such as catalyst/light absorber, nanoscale photosynthetic unit/proton conducting membrane, metal oxide core/silica shell, is critical for the improvement of charge transport efficiency.
- Charge transport efficiency across interfaces is a key scientific gap in our push towards viable integrated solar fuel systems.
- Atomic resolution imaging of these interfaces, including during photosynthetic action will be a powerful tool for accelerating progress towards efficient solar fuel generating systems.



Matthew Libera
Stevens Institute of Technology

Spectroscopic Imaging of Hydrated Materials

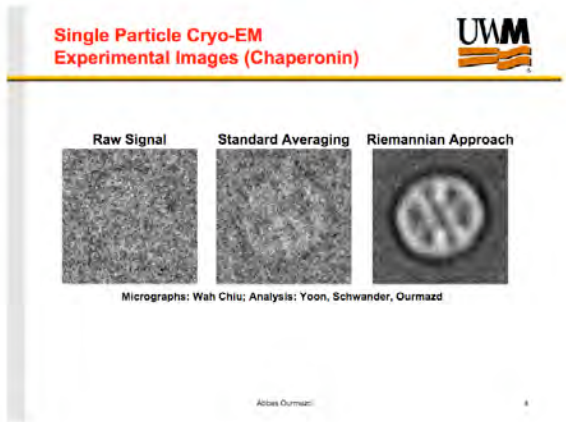
- Heavy element staining techniques to generate TEM contrast based on elastic electron scattering are powerful but are not well suited to a growing number of problems.
- Spectrum imaging can generate contrast based on the differential inelastic scattering between different specimen components and can be made fully quantitative.
- Because of the sensitivity of unstained soft materials to incident electrons (damage), we must speak of dose-limited resolution rather than optics-limited resolution.
- Dose-limited resolution can be further improved using monochromated sources to achieve better energy resolution and by using advanced data processing techniques to mine experimental datasets for significant spectral features.



David Prendergast
MF, LBNL

First-principles Simulations of Damage in Materials Induced by Core-Level Excitation

- Our goal is to explore the impact of exposing soft/hard interfaces, as found on nanocrystal surfaces, to highly focused electron beams.
- We used first-principles electronic structure techniques to simulate core-level excited states of small organic molecules to examine their chemical stability.
- To this end, we developed a molecular dynamics sampling approach to explore excited state trajectories, revealing the possibility of moeity-selective energy-dependent chemistry induced by core-level excitation



Abbas Ourmazd
UWM

Divide & Conquer: EM of Radiation-Sensitive Materials

- Soft materials consist of conformationally heterogeneous sets of building blocks with extreme radiation sensitivity. It has therefore been difficult to determine their atomic structure.
- New analytical approaches based on Riemannian geometry allow the reconstruction of the 3D structure of each member of the set at ultralow dose.
- Results from cryo-EM data already show the enormous enhancement in signal/noise possible with such techniques (above slide, credits: Ourmazd, Schwander, Yoon, Chiu, unpublished.)
- In combination with through-focal series and/or discrete tomography, it should be possible to determine the 3D structure of radiation-sensitive hard/soft interfaces likely to play a key role in artificial photosynthesis and energy storage.

IDEAL SoftTEAM CONFIGURATION FOR (MY) BIOLOGICAL APPLICATIONS

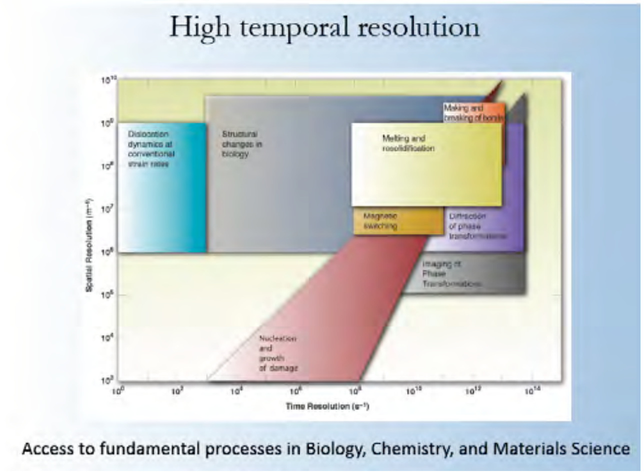
FEATURE	VALUE ADDED
X-FEG Gun	Greater brightness allows to decrease the cut-on frequency for phase contrast while keeping exposure times short
TEAM Cryo-stage	Improved stability at high tilt
Transfer Lens	Capable of accepting new developments in phase-plate technology Lower cut-on frequency for any given design of phase plate
Energy Filter	Essential for tomography of thick specimens
8kx8k LBNL CMOS Detector	Large number of pixels Near-perfect MTF Near-perfect DQE

Bob Glaeser
UC Berkeley / LBNL

Phase Plate Developments for Biological Structures

- Inclusion of Zernike phase contrast is certain to be essential in any cutting-edge electron microscope that is intended for biological and soft-matter applications, but the development of such devices is still far from mature.
- It is strongly recommended that the SofTEAM microscope incorporate a transfer lens module for the phase plate, so that new developments can be incorporated as they evolve.
- As is summarized in the table, the inclusion of a transfer lens module along with other existing and planned features of the SofTEAM microscope would provide an instrument whose capabilities are far beyond those of any instrument that

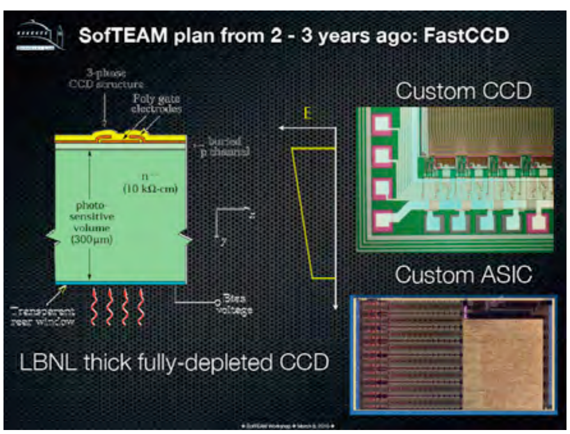
currently exists or that, to my knowledge, is even being planned elsewhere in the world.



James Evans
UC Davis

Imaging Biological Processes with an Aberration Corrected Dynamic TEM

- We are working to evaluate whether the DTEM can "outrun" the degrading imaging effects of beam induced damage / drift for cryo-EM.
- Optimization of a continuous flow fluid holder for biological imaging includes the development of thermal regulation and a mixing chamber, and control of the window thickness and spacing.
- A major goal is to capture single-shot conformational changes of proteins. We are also attempting to acquire real-time movies of biological processes with simultaneous nanosecond and nanometer resolution.
- We are also working to evaluate 3D reconstruction capabilities within a fluid environment.



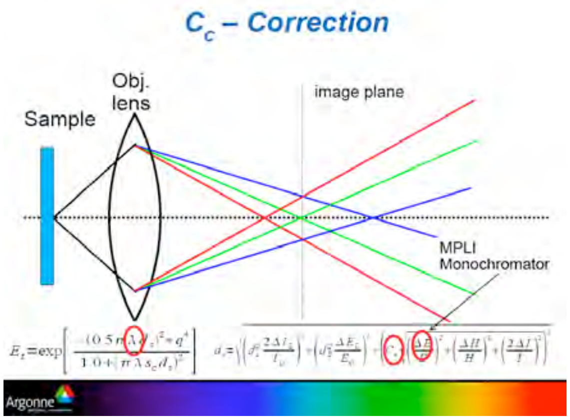
Peter Denes
LBNL

Modern Detectors for Electron Microscopy of Soft Materials

- LBNL has been engaged in the development of advanced electron detectors for several years. Developed first under an LDRD and then by the TEAM project, CMOS Active Pixel Sensors capable of single electron detection with a high signal-to-noise ratio and 400 frame/s readout were developed.
- Such detectors are very well suited to higher ($\geq$ 200 keV) energies, but not to lower (<60 – 80 keV) energies. Direct electron detectors based on fully-depleted

monolithic silicon sensors with a thin entrance window are ideally suited for these lower energies, which will be an important feature of SofTEAM.

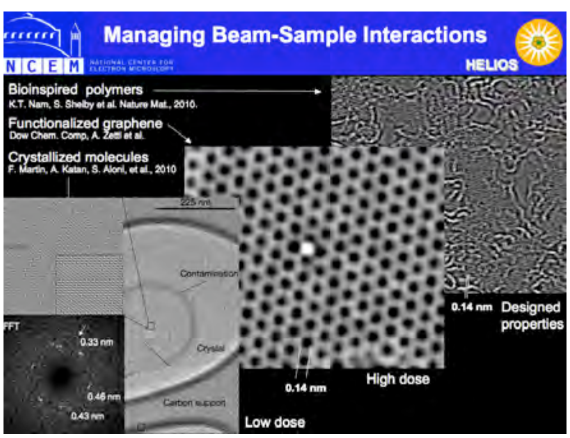
- Our original concept was to use a very high speed CCD direct detector developed and deployed at LBNL for x-ray applications. In the meantime, our ongoing developments in Silicon-on-Insulator (SOI) technology suggest that SOI could be ideal for SofTEAM. In addition to the high performance of a fully-depleted detector, SOI would permit the re-use of the mechanics and back-end electronics developed under the TEAM project.



Bernd Kabius
ANL

Application of a Chromatic Aberration Corrector for Biological Materials

- In the past, Cs correction has enabled direct interpretation of images. Beam convergence and beam tilt became independent parameters.
- Cc correction has added additional capabilities. It allows for better investigation of thick samples including higher pressures and liquids and improves on tomography images taken at high tilt angles.
- Analytical electron microscopy directly benefits from Cc correction (high resolution EFTEM, elemental mapping and imaging in the loss region).

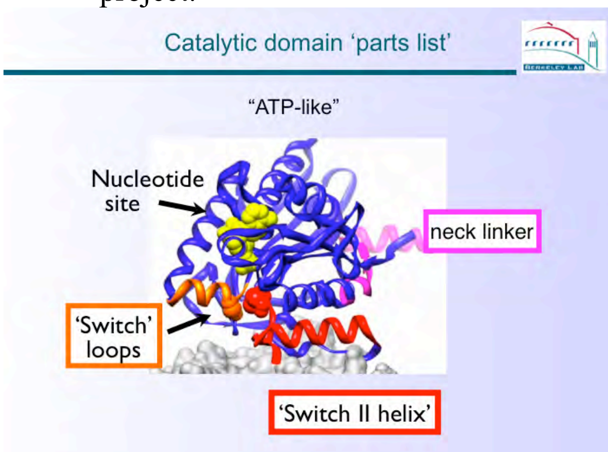


Christian Kisielowski
NCEM / LBNL

Contrast Enhancement in Electron Microscopy: From Resolution to Time Evolution

- With the conclusion of the TEAM project atomic resolution microscopy has reached physical limits around 0.5 Å and sensitivity becomes arguably more important than resolution.
- Harvesting spatial frequencies (phase plates and resolution) is essential and possible by using a Cc corrector in combination with exit wave reconstruction to mimic the presence of a Zernike phase plate.

- Dose limitations can be relaxed by materials design, by exploring new detection techniques (divide & conquer, hit & destroy) and by using atomic resolution microscopy between 20 kV and 300 kV, which was fostered by the TEAM project.



Ken Downing
LBNL

State of the Art in Cryo TEM

- This presentation provided an overview of the field of cryo TEM for biological applications, where it is possible to derive atomic structures directly from cryo-EM data at a resolution of 3.5 – 4Å.
- These techniques are exposure limited to ~10 e/Å^2, resulting in a need to average many motifs, commonly with particles of very high symmetry.
- Cryo EM can identify structural motifs in tomographic reconstructions, but currently only at a resolution of 30-50Å, we still need much better images with thicker specimens & at higher tilt angles.
- There is a clear need for faster, lower-noise detectors.
- We need better ways to deal with multiple scattering in thick samples.

List of Participants

This workshop was widely publicized in the scientific community. Invitations were sent by e-mail to 4,500 individuals and institutions. The composition of the target audience was identical to that of the nanoscience centers and the electron scattering facilities, including universities, industry and national laboratories as well as targeted institutes in the international arena. While the majority of the participants were from LBNL and UC Berkeley, the broad scientific appeal of the topic is apparent from the demographic diversity of the participants.

The workshop was attended by 75 registered participants, reflecting the great interest of the community in advanced microscopy techniques and instrumentation for materials with both soft and hard components. The number of actual participants was estimated to vary from 80 to well over one hundred at different points during the day.

Registered participants were:

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